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REDUCTION OF TARGET DETECTABILITY BY LASER PROTECTIVE MATERIALS.

April 1976

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Target detectability has been measured as a function of target size and luminance levels. The reduction of detectability by laser safety goggles (American Optical Model 585 and Glendale Optical Model LGS-R) has been determined for achromatic targets. The effects of target color rendition are considered. Luminous transmission appears to be the most important parameter for detection. Blue targets, either natural or rendered blue by protective materials, require more contrast for detection.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

INTRODUCTION

An ideal laser protection material will provide the required optical density at the laser wavelength and be transparent at all other wavelengths. Practical bulk absorbers are broad band absorbers which greatly reduce the transparency. The degree of transparency is specified by the luminous transmission which is the integrated effect of the spectral transmission on the standard photopic observer. The luminous transmission is a useful figure for neutral density filters which uniformly reduce the intensity of a scene. It does not describe the spectral characteristics of the material and therefore is perhaps a misleading parameter for laser protective materials. It does not relate how visual functions such as color discrimination, intensity discrimination, detection and identification may be affected.

A "quality factor" or "figure of merit" has been used to assess the perceived image of infrared systems[1] and photographic pictures[2]. The factor combines the image sharpness and system background noise with the eye's ability to resolve images. The factor is extremely useful for black and white displays where the eye detects luminance changes only. With colored images the eye will detect differences in color even if the luminance is constant. The quality factors used by Synder[1] or Granger[2] must then be expanded to include color contrast.

Although there are many ways to formulate a quality factor, the present study examines a method of combining luminous transmission with the detectability of low contrast targets.

The present study examines how detectability of low contrast targets is affected by two popular ruby laser protectors (American Optical Corp., Model 585; and Glendale Optical Co., Model LGS-R). In order to study the effect of color rendition only, neutral density filters were used to equate the luminous transmission of the two goggles. Theoretical considerations of how these goggles might perform is given. To obtain the effects of protective materials on detectability, the contrast required for the detection of various achromatic targets was measured. The targets consisted of fourteen gratings which subtended visual angles from 2.26 minutes per line pair up to 68.4 minutes per line pair.

THEORY

Contrast sensitivity functions depend upon, (a) the optical modulation transfer function of the eye responsible for image formation on the retina, (b) retinal topology, and (c) higher neural interactions. We will consider each in turn.

The primary chromatic aberration of the eye is longitudinal chromatic aberration. When viewing white light, the eye optimally focuses on one wavelength and all other wavelengths are more or less out of focus. As shown in Figure 1, this optimal focus is about 575 nm.[3] Optimal focusing leads to maximum visual acuity. The focus difference in the red (from 575 nm to 700 nm) is small. However in the blue (400 nm to 500 nm) the difference is large. Clearly, blue targets in a normal environment (i.e., if white light controls the focus) will be somewhat out of focus and thereby more difficult to recognize.

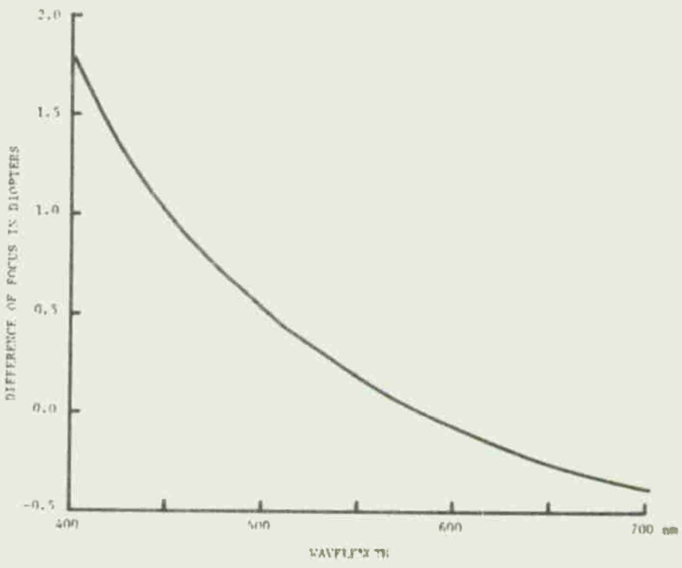

Figure 1. Chromatic Difference of Focus (from Reference 3).

If a relatively narrow spectral band of illumination is used one might suppose the eye focuses roughly in the center of that band. Since the eye exhibits lower acuity in the blue we may assume that the eye will always attempt for maximum focus and thereby focus at wavelengths close to 575 nm rather than in the center. For the laser safety goggles under consideration, one appears blue and the other green. The maximum transmission for LGS-R occurs at 475 nm whereas it is 520 nm for A0585. From purely chromatic aberration considerations we might assume that detection would be poor when using the LGS-R goggle.

However, in monochromatic light, except in the deep blue the eye is able to focus properly if corrective lenses are used.[4] But Porkorny,

et al.[5] has shown that even with corrective lenses visual acuity is lower in the blue (465 nm) which he attributes to complex retinal and neural factors.

Green[6] has shown that for equal luminance targets, short wavelength (blue) targets require higher contrast to be detected. This he attributed to the fact that there are few blue cones in the retina.

Granger carries this one step farther into the neural processing of the eye. He[7] has shown that the neural yellow-blue system is less efficient in detection than the neural red-green system. In contrast, Farnsworth[8] has shown that for detection of small targets, the eye suffers small-field tritanopia. This means that the yellow-blue system is unimportant at threshold. Furthermore Judd and Eastman[9] state that the effect of the R-G system is reduced by a factor of 10 at threshold. Thus the W-Bl system is the most important system. To account for the increased contrast required in the blue region of the spectrum, Judd and Eastman show that the inherent chromatic aberrations of the eye account for 82% of the difference in detectability. The approach of Judd and Eastman's allows one to calculate the visibility of targets from the spectral content of the target and background but does not include the effect of target size.

All researchers arrive at the same end point: blue targets require higher contrast for detection. It is a combination of, (a) inherent aberrations, (b) neural processing that causes the yellow-blue system to be either ineffective or inefficient, and (c) lack of blue cones.

Although many methods may be used to calculate a "quality factor", we will follow Granger's[7] approach. The data presented is insufficient to justify this quality factor as the only unique approach. But the calculations will demonstrate the rationale involved.

The eye's neural system appears to follow a color opponent system.[10] The chromatic responses, white-black, red-green and yellow-blue systems, are related to the CIE tristimulus values by,

$$\text{W-Bl} = Y$$

$$\text{R-G} = X - Y$$

$$\text{Y-B} = 0.4X - 0.4Z$$

Note that the W-Bl system is identical to the CIE photopic observer (Figure 2).

If different colored low contrast images excite the W-Bl system equally, then according to Granger, the image whose spectral component excites the R-G system maximally will have the highest probability of detection. Any image whose spectral components excite the Y-B system maximally will have a smaller probability of detection.

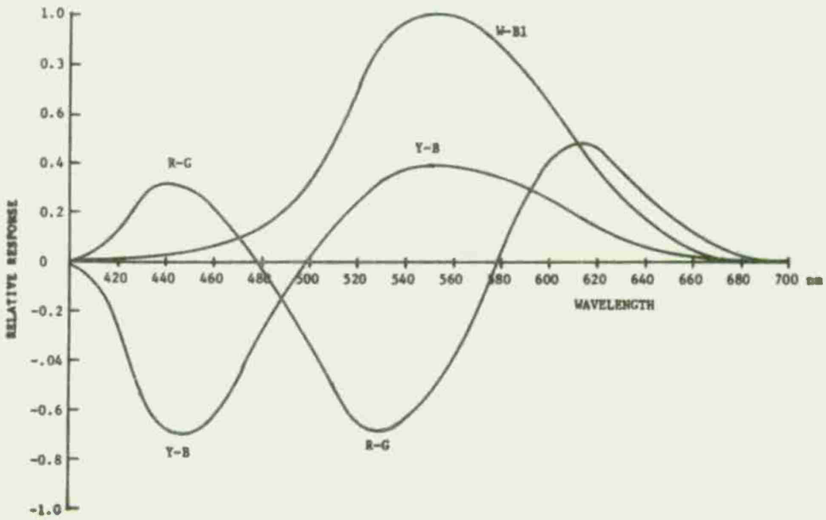

Figure 2. Relative Responses of the Three Neural Color Opponent Processes. The Positive Values Indicate an Increased Firing Rate of the Neurons. A Negative Value Indicates a Decreased Firing Rate Relative to the Resting (Spontaneous) Firing Rate.

The relationship between contrast sensitivity and luminous transmission is not fully understood. However Granger and Heurtley[11] proposed a color image quality factor which correlated with subjectively perceived quality assessment of color images. This factor is represented as,

$$Q = \sum_i C_{fi} B_i W_i$$

where,

$$B_i = \sum_\lambda T_\lambda S_\lambda R_{\lambda i} \, \Delta\lambda$$

and, T_λ is the transmission of the material at wavelength λ,

S_λ is the source intensity,

$R_{\lambda i}$ is the color opponent system,

W_i is a weighting factor,

C_{fi} is contrast sensitivity of each system for each spatial frequency f.

B_1, B_2, and B_3 represent the contribution from the R-G, Y-B, and W-Bl systems. When B is normalized, the luminous transmission is obtained.

i.e.,

$$LT = \overline{B}_3 = \frac{\sum_\lambda T_\lambda S_\lambda R_{\lambda 3} \Delta\lambda}{\sum_\lambda S_\lambda R_{\lambda 3} \Delta\Lambda}$$

The weighting factor relates how the color opponents systems should be added together. The exact values of W_i and C_{fi} are not known for the three systems.

To determine these unknowns two ruby laser protective materials (American Optical 585 and Glendale LGS-R) and a neutral density filter were chosen. The spectral transmission is shown in Figure 3. A neutral density filter of 0.4 units of density was placed in front of the American Optical Model 585 goggles so that it would have the same luminous transmission as the Glendale Optical LGS-R goggle. A second neutral density filter was also chosen to have the same luminous transmission so that the effect of uniform attenuation could be measured. Unless otherwise stated all tests and calculations were performed with the 0.4 ND filter in front of the A0585 goggle. Using a light source whose color temperature was 3200°K the relative values of B_i were calculated. The results are tabulated in Table 1.

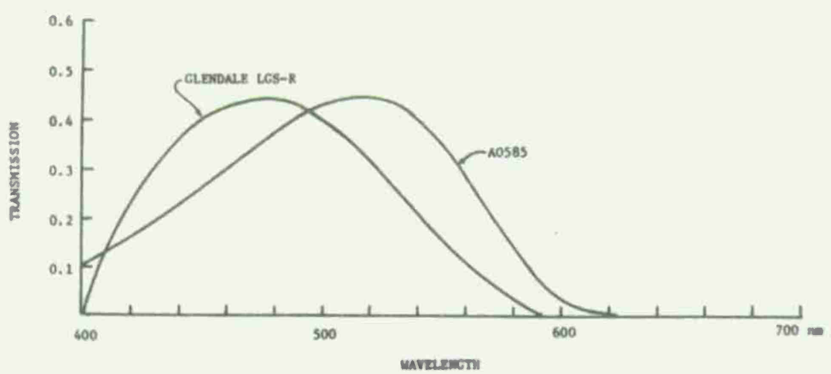

Figure 3. Spectral Transmission of the American Optical Model 585 Ruby Goggle and the Glendale Optical Model LGS-R Ruby Goggle.

Table 1. Relative Values of B_i.

Goggle	B_1 (R-G)	B_2 (Y-B)	B_3 (W-Bl)
A0585	-43	-30	+92
LGS-R	-46	+14	+92
ND	+14	+21	+92

As seen in Table 1, these materials have one nice property. Namely since B_1 is the same for both A0585 and LGS-R then any difference in contrast sensitivity can be attributed to the Y-B system.

EXPERIMENTAL

To determine C_{fi} and W_i, threshold of detection of various gratings of different spatial frequencies were obtained using four subjects. The experimental setup is shown in Figure 4. The subject could adjust the neutral density wedge about his own threshold. He would simply increase the density until the grating faded into the background and then reverse the wedge until the grating just appeared on the screen. By using a potentiometer attached to the wedge, the optical density of the wedge could be followed on a strip chart recorder. The system was calibrated so that the wedge setting was related to the contrast. The contrast is defined as target luminance divided by the background luminance. Each grating was presented vertically and for about one minute. In this time, the subject made about 10 excursions about his threshold. Threshold is defined as the average value of the excursions. This threshold corresponds to a 50% probability of detection. Using Blackwell's average probability curve[12] the minimum to maximum excursion corresponded to a probability of 15%-85% for two observers and 25-75% for the other two observers. Fourteen gratings which subtended visual angles from 2.26 minutes per line pair to 68.4 minutes per line pair were used. The intensity of the screen was varied from 0.35 foot lamberts to 1700 foot lamberts. These light levels corresponding to known levels of illumination are shown in Table 2.

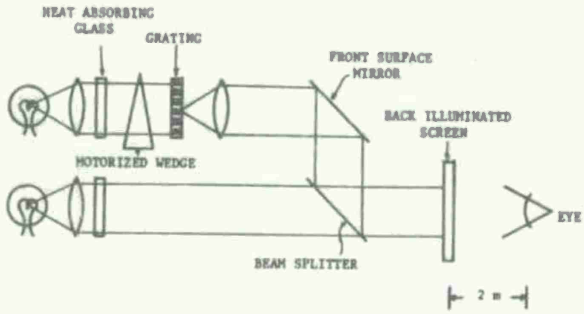

Figure 4. Schematic of Experimental Setup.

Table 2. Relationship Between Various Luminance Levels Used.

Log Foot Lamberts	Horizon Sky Luminances		Visual System
-6	absolute threshold		
-5	overcast starlight		Scotopic Rods
-4	starlight		
-3	quarter moon		
-2	full moon		
-1	deep twilight		
0	twilight	THIS STUDY	Mixed
1	very dark day		Photopic Cones
2	overcast sky		
3	full daylight		
4			
5			
6			

RESULTS

The contrast sensitivity C_{fi} obtained is the usual "J-shaped" curve.[13] However the hook of the J is caused by the experimental procedure. Hoekstra, et al.[14] have shown that the threshold depends upon the number of cycles in the stimulus when less than 8 complete cycles are present for the 2.1 degree circular screen, this translates to 16 minutes per line pair. Therefore rather than report experimental artifact, only the data below 16 minutes per line pair is presented. Using Johnson's[15] criterion for target detection (i.e., 50% probability of detection corresponds to detection of one line pair) the data has been converted from minutes per line pair to angular width. The contrast required for detection for the three goggles are shown in Figures 5-12. The range R is obtained by multiplying the abscissa by the diameter of the target d. For example if the target diameter is 1 meter then the abscissa is the range in meters. The ordinate is the contrast required for a 50% probability of detection.

DISCUSSION

In all cases except the lowest intensity (0.35 and 0.67 FT-L) and the highest intensity (1700 FT-L) targets viewed through the Glendale LGS-R require more contrast than the A0585 or neutral density filter. Scanning across the graphs, it can be seen that as luminance decreases, the contrast required increases. This contrast difference is much greater than the differences among the three materials at a fixed intensity level. Both the A0585 and neutral density provide about equal performance even though $\Delta B_1 = 57$ and $\Delta B_2 = 51$. It would appear then that the weighting factors are such that B_1 and B_2 cancel. Thus the quality factor may have a form such as,

$$Q = a(B_1 - B_2) + bB_3$$

Then,

$$Q = -13a + 92b \text{ for A0585}$$

$$Q = -60a + 92b \text{ for LGS-R}$$

$$Q = -7a + 92b \text{ for ND}$$

Since the luminous level has such a large effect on the contrast, $b \gg a$. From the A0585 and LGS-R curves, the difference in contrast can be attributed to $\Delta B_2 = 44$. Thus we find that the Y-B system has a poorer contrast response then the R-G system. This is consistent with Granger's findings.

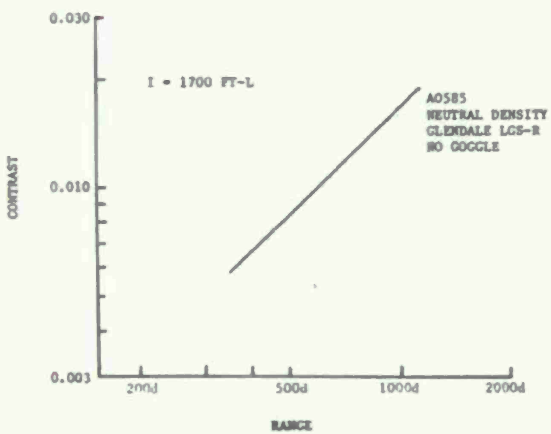

Figure 5. Target-Background Contrast Required for 50% Probability of Detection as a Function of Range and Target Diameter d with Background Luminance of 1700 FT-L.

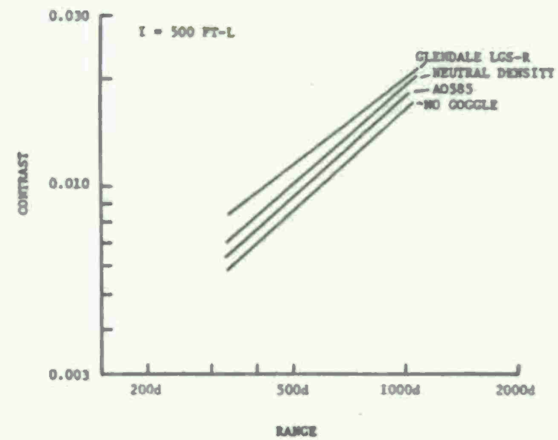

Figure 6. Target-Background Contrast Required for 50% Probability of Detection as a Function of Range and Target Diameter d with Background Luminance of 500 FT-L.

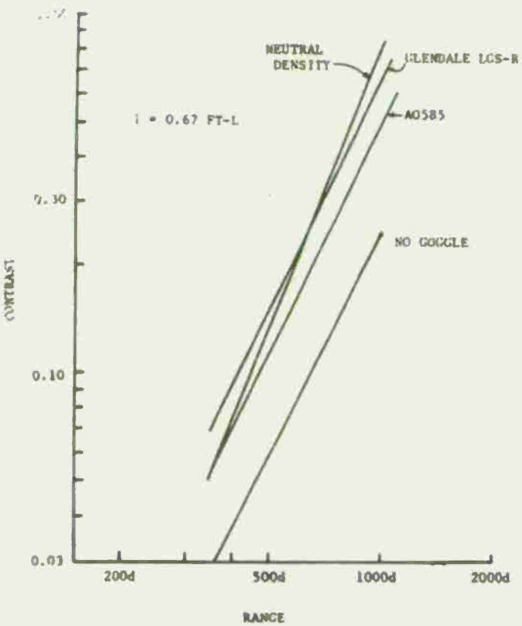

Figure 7. Target-Background Contrast Required for 50% Probability of Detection as a Function of Range and Target Diameter d with Background Luminance of 106 FT-L.

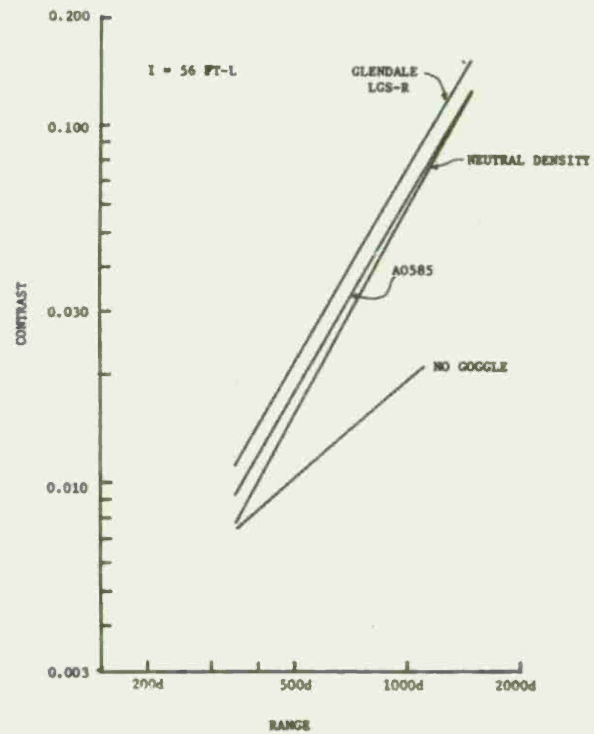

Figure 8. Target-Background Contrast Required for 50% Probability of Detection as a Function of Range and Target Diameter d with Background Luminance of 56 FT-L.

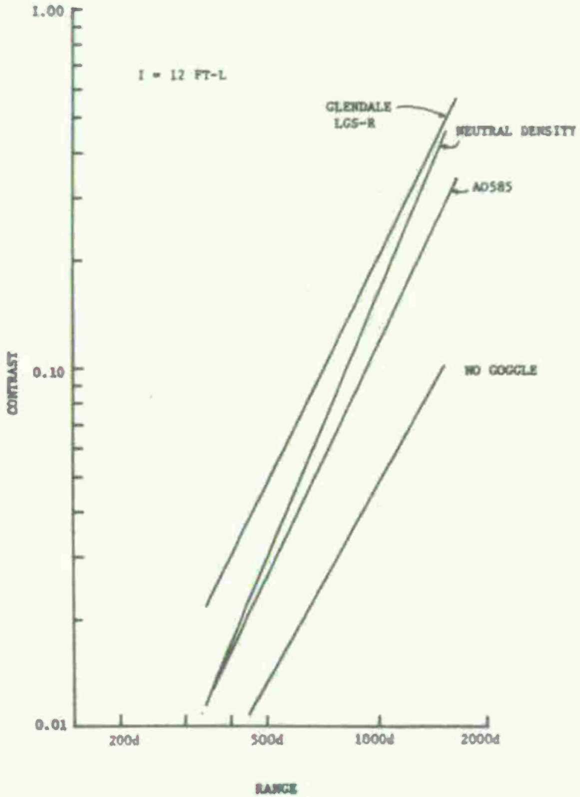

Figure 9. Target-Background Contrast Required for 50% Probability of Detection as a Function of Range and Target Diameter d with Background Luminance of 12 FT-L.

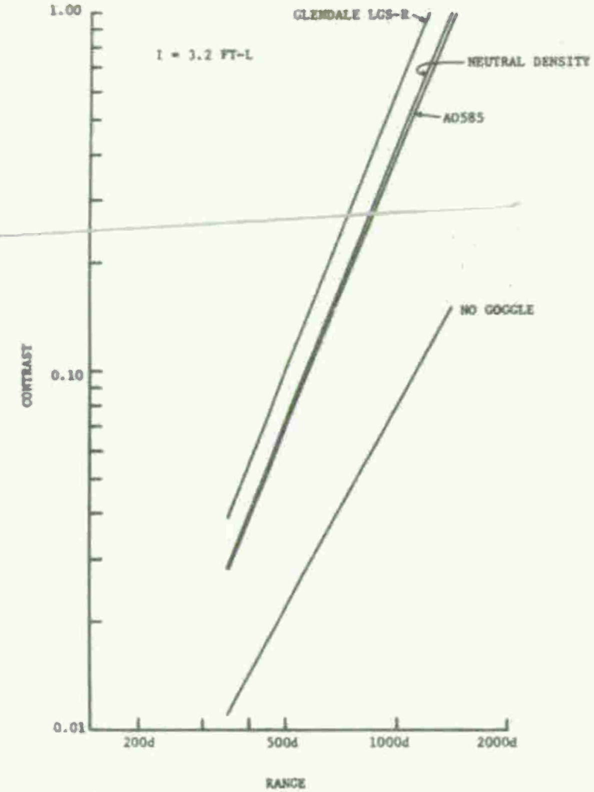

Figure 10. Target-Background Contrast Required for 50% Probability of Detection as a Function of Range and Target Diameter d with Background Luminance of 3.2 FT-L.

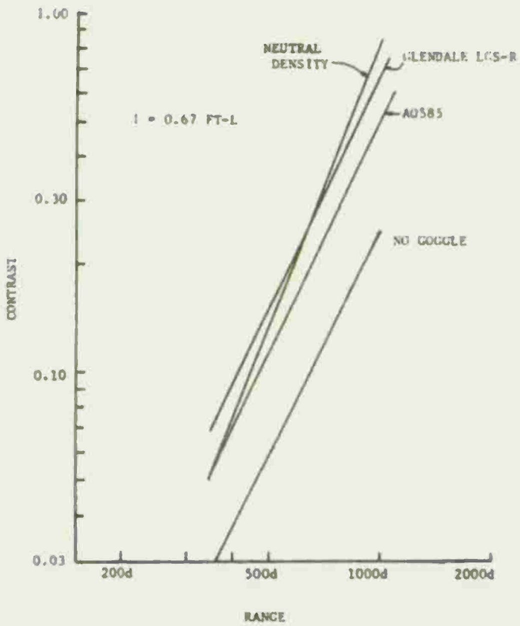

Figure 11. Target-Background Contrast Required for 50% Probability of Detection as a Function of Range and Target Diameter d with a Background Luminance of 0.67 FT-L.

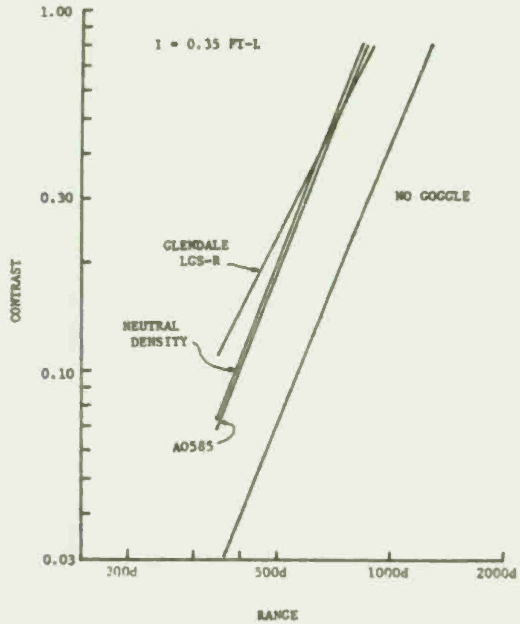

Figure 12. Target-Background Contrast Required for 50% Probability of Detection as a Function of Range and Target Diameter d with a Background Luminance of 0.35 FT-L.

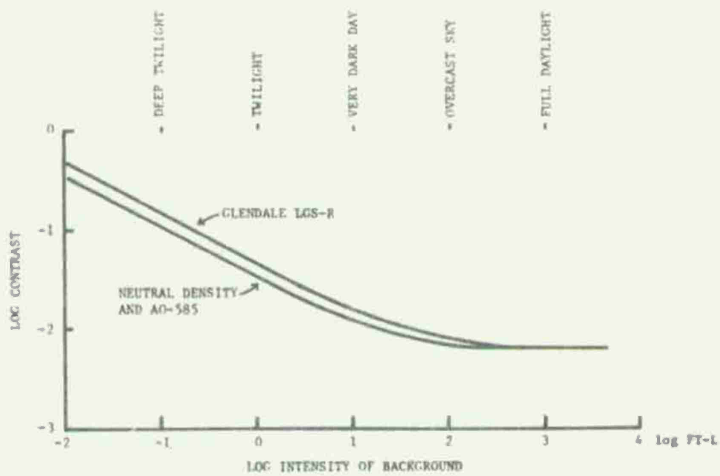

Figure 13. Target-Background Contrast Required for 50% Probability of Detection as a Function of Background Intensity for a Target Subtending 6.6 Minutes of Arc.

Although Granger and Heurtley's formulation does fit the experimental data, the data does not permit the ability to distinguish between a color opponent theory and inherent aberrations. Nor does the data suggest that this quality factor is unique.

The light intensities for representative sky luminances are shown in Table 2. The light intensities listed are those for the luminance of the screen. The actual intensity reaching the eye is reduced by the luminous transmission of the material (LT $\approx$ 10%). For the low intensities both rods and cones are functioning. The rods allow only achromatic vision. The protective materials were matched for equal photopic luminous transmission. Thus at the lower intensities (0.35 and 0.67 FT-L) the luminous intensity is no longer equal.

At the high intensities, there is no difference in detection capability. This is evident in Figure 13 where the data has been replotted as a function of intensity for a fixed visual angle. Simply stated, for high intensities, the contrast required for detection is independent of the intensity. At low intensities the LGS-R goggle requires 40% more contrast when compared to the neutral density or AO585 with equal luminous transmission. Apparently the Glendale LGS-R goggle, has no deleterious effect on detection threshold at high intensities. The shape of Figure 13 is identical to those obtained by Blackwell.[12]

Because these are static tests, there is no way of predicting how vision will be degraded in a dynamic case such as in searching or tracking.

These tests were performed on color normal subjects. Each subject had or was corrected for standard visual acuity (20/20). Since approximately 5% of the population is color blind, it is of interest to study the effect of laser protective materials on this segment of the population. One color blind individual was available for these tests. Initial testing on the Farnsworth-Munsell 100 Hue Test indicated that he was a strong deutan. When wearing the LGS-R, his color discrimination axis appeared to shift from that of a deutan to that of a protan. On the grating tests, the variability was so high that the data could not be used.

Two long-term adaptation tests were performed. The LGS-R goggle was worn for three hours. The pre- and post-results on the target detection tests were identical.

SUMMARY

1. Luminous transmission appears to be the most important parameter in detecting achromatic low contrast targets.

2. Blue targets, either natural or rendered blue by protective material, require more contrast for detection. In particular, under conditions of overcast daylight or darker, the LGS-R goggles require 40% more contrast than the A0585 with reduced transmission. Since the standard A0585 has a much higher luminance transmission, it will provide greater detection ranges than the LGS-R.

3. Laser protective materials will not degrade detection capability for high intensity targets.

4. Long term (three hours) adaptation does not change detection ability.

5. The need for a quality factor is more evident when detecting real targets (i.e., colored targets on colored background). The approach used in this study required further investigation before a definitive quality factor can be employed.

REFERENCES

1. H. L. Snyder, "Perception of Displayed Information", edited by L. Biberman, Plenum Press (1973).

2. E. Granger and K. Cupery, "An Optical Merit Function (SQF) Which Correlates with Subjective Image Judgements", Photographic Sci. and Eng. 15, 221 (1972).

3. G. Wald and D. R. Griffin, "The Change in Refractive Power of the Human Eye in Dim and Bright Light", J. Optical Soc. Am. 37, 321 (1947).

4. Y. Le Grand, "Light, Colour and Vision", (Translated by R. Hunt, J. Walsh and F. Hunt), J. Wiley (1957).

5. J. Porkorny, Ch. H. Graham and R. N. Lanson, "Effect of Wavelength on Foveal Grating Acuity", J. Optical Soc. Am. 58, 1410 (1968).

6. D. Green, "The Contrast Sensitivity of the Colour Mechanisms of the Human Eye", J. Physiol. 196, 415 (1968).

7. E. Granger, private communication.

8. D. Farnsworth, "Tritanomalous Vision as a Threshold Function", Farbe 4, 185 (1955).

9. D. Judd and A. Eastman, "Prediction of Target Visibility from the Colors of Target and Surround", Illuminating Engineering 66, 256 (1971).

10. Hurvich and Jameson's theory can be found in many vision books. See for example, "Vision and Visual Perception", C. Graham, editor, John Wiley (1965).

11. E. Granger and J. Heurtley, "Specification of Color Image Quality", J. Optical Soc. Am. 63, 1301 (1973)(Abstract WK 15).

12. H. R. Blackwell, "Contrast Thresholds of the Human Eye", J. Optical Soc. Am. 36, 624 (1946).

13. Numerous studies on contrast sensitivity have been performed. See for example, F. L. VanNes and M. A. Bonman, "Spatial Modulation Transfer in the Human Eye", J. Optical Soc. Am. 57, 401 (1967).

14. J. Hoekstra, D. P. Van Der Goot, G. Van Den Brink and F. A. Bilsen, "The Influence of the Number of Cycles Upon the Visual Contrast Threshold for Spatial Sine Wave Patterns", Vision Research 14, 365 (1974).

15. J. Johnson, "Analysis of Image Forming Systems", in Image Intensifier Symposium, Ft. Belvoir, Virginia, October 1958, AD 220160.

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